image is a mathematical device which applies strictly only in the case where the earth is assumed to be an infinitely extended plane, in which case, however high the aerial is, the negative image is effective at distances large compared with this height. The surface of the earth being actually spherical, a modification to the image theory must be made presumably at heights which become comparable with the earth's radius and for distances at which the curvature of the earth becomes appreciable. I therefore think that the aerial must be raised to a height much greater than one or two wavelengths before the negative-image theory has to be modified. For this reason I think that the image theory has to be applied to the Franklin type of aerial. This aerial is, however, of sufficient height to supply the necessary horizontal radiation.

THE PERFORMANCE OF AN INTERMEDIATE-FREQUENCY AMPLIFIER.*

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Summary.

The paper gives the results of measurements carried out on an intermediate-frequency amplifier forming part of a commercial supersonic heterodyne receiver designed for broadcast reception. The amplifier is described, with special reference to the coupling transformers. Slight modifications of the circuit are necessitated by the method of test, but it is concluded that the conditions of measurement approximate closely to those of normal use.

Three representative types of valves are employed in turn and it is shown that, for a prescribed standard of cut-off at the extremes of the side-bands, the amplification obtainable increases with the mutual conductance of the valves. The best type of valve to use in various circumstances is deduced from the results obtained.

While much progress has been made during the last few years in the theory of high-frequency amplification which is of great assistance to the designer, up to the present it can hardly be claimed that it is possible completely to forecast the performance of a commercial design of amplifier on theoretical grounds, as one would in the case of the majority of electrical appliances. For this reason it is desirable to carry out actual measurements of performance in order to ascertain to what extent theoretical considerations are reflected in actual results. Unfortunately, as has been pointed out in recent work on the subject,† such measurements are not by any means easy to carry out in a manner which gives a fair indication of the performance under working conditions.

The difficulties are somewhat reduced when, as in the work to be described, the apparatus is only called upon to deal with a narrow band of relatively low radio frequencies. These measurements were carried out on the intermediate-frequency amplifier of a supersonic heterodyne receiver designed primarily for broadcast reception, and they supply information concerning the effect of valve characteristics on amplification, selectivity and side-band cut-off, and self-oscillation; and also the effect of input amplitude on amplification, and of damping on resonant frequency.

The method is quite straightforward, and consists in feeding the input with an alternating e.m.f. of known amplitude and frequency, and measuring the output by what is, in effect, a valve voltmeter. The valves involved are the first rectifier, two amplifying valves and the second rectifier, and the amplification is taken as the ratio of the alternating e.m.f. developed at the grid of the second rectifier to that applied to the grid of the first rectifier. The disturbing effect of a measuring instrument for indicating the output voltage is entirely avoided by making the last valve itself serve as the voltmeter, thus preserving working conditions. The first valve is the only one which undergoes any alterations, as its grid-filament input is practically short-circuited. The anode current, and consequently the permeability of the iron core of the first transformer, are not quite the same as when the local oscillator used in the complete receiver throws a fairly large bias on the first grid, but this slight divergence from practical conditions is not sufficient to cause serious error.

The input is derived from a valve oscillator, shown in Fig. 1, covering the required frequency range, loosely coupled to a circuit containing a thermo-couple milliammeter and a stretched wire W about 15 cm long, of 30 S.W.G. Eureka, one end of which is connected to the earthed side of the amplifier. The first grid is tapped on to this wire, and, as the resistance can be easily found, the e.m.f. applied to the amplifier is also known. The coupling coil L_3 is of a much lower inductance than L_1; the latter is coupled fairly loosely to L_2 in order to minimize harmonics. The greatest

* Reprinted from *Journal I.E.E.*, 1927, vol. 65, p. 644.
† H. A. Thomas: "The Performance of Amplifiers," *Journal I.E.E.*, 1926, vol. 64, p. 253, and *Proceedings of the Wireless Section*, 1926, vol. 1, p. 12.

difficulty is to avoid stray coupling to the amplifier, and it is necessary for it to be entirely screened in an earthed sheet-iron box. The terminals and potentiometer control are brought out through bushes, and overlap on each side as much as possible. For extremely accurate work it would be necessary to adopt greater precautions at these points, and to enclose the batteries, etc., but for the purpose in view this was not deemed necessary. With the input short-circuited, it was not possible to detect appreciable stray pick-up unless the amplifier was adjusted more critically than was the case in any of the measurements.

The output is indicated by the depression of the second rectifier anode current, shown by the milliammeter. This valve is independently calibrated from known e.m.f.'s provided in a similar manner to the input, but a larger non-reactive resistance than W is used for this purpose. The grids of the two amplifying valves can be set to biasing potentials as shown on the voltmeter, thus controlling the damping in the usual way. The output filter, consisting of two condensers and air-core choke, is that used to prevent intermediate-frequency currents from straying into the low-frequency amplifier.

The coupling transformers are shown diagrammatically in section in Fig. 2. The secondary is wound in two sections, one each side of the primary, each section consisting of 1 500 turns of No. 40 s.s.c. copper wire wound honeycomb fashion. The primary is a similar coil with 700 turns of the same wire. All the coils are mounted on insulating material around a core of 23 sheets of iron, 1·75 in. long and 0·14 sq. in. total section. The whole assembly is mounted in a cylindrical brass case and filled in with wax. The connections are brought out to four bushed terminals at the top. The screening is completed by a bottom disc and the case is earthed.

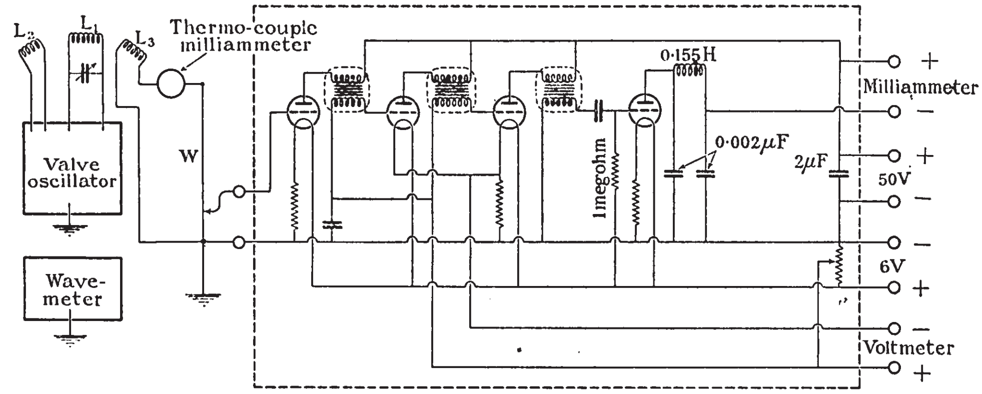

FIG. 1.—Method of measuring intermediate-frequency amplification.

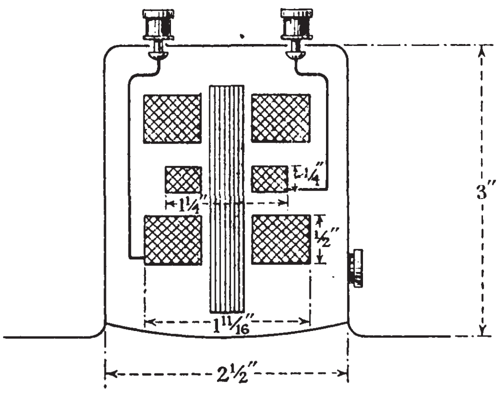

FIG. 2.

The inductance of the primary coil unmounted is 13 500 μH, and of a single secondary coil 61 700 μH. The rated working frequency of the complete transformers is 47·5 kilocycles, but in practice they are assembled in sets of three, bearing test-figures which are as nearly as possible the same and in no case more than $\pm$ 0·5 kilocycle distant from some frequency between 45 and 50 kilocycles. The figures for the particular transformers used in the amplifier in the present case were 47·3, 46·9 and 47·3 kilocycles respectively. The test gear used to obtain these results is arranged to indicate the frequency of maximum amplification when connected with short leads between valves of type A.

TABLE 1.

Valve	Anode A.C. resistance	Amplification factor, μ	Mutual conductance	
	ohms		micromhos	
A	11 000	8	726	HL512
B	45 000	21·8	485	H512
C	19 500	18·6	955	Mullard PM

In order to obtain a uniform basis for comparing results when using different valves, an output e.m.f. of approximately 0·5 volt at resonance was arranged for in each case, this being a value of carrier amplitude which gives normal loud-speaker strength when followed by two low-frequency stages.

Three types of valve, referred to as A, B and C,

were employed in turn in the two amplifying stages proper; the same input and output valves were retained in each case. The two in use at any one time were chosen as having substantially the same characteristics; the average for the two is shown in Table 1.

Fig. 3 shows curves of amplification plotted against frequency for these three types of valves and for various settings of the potentiometer which forms the volume control in the complete receiver. Amplification is plotted to a logarithmic scale, as this is more convenient

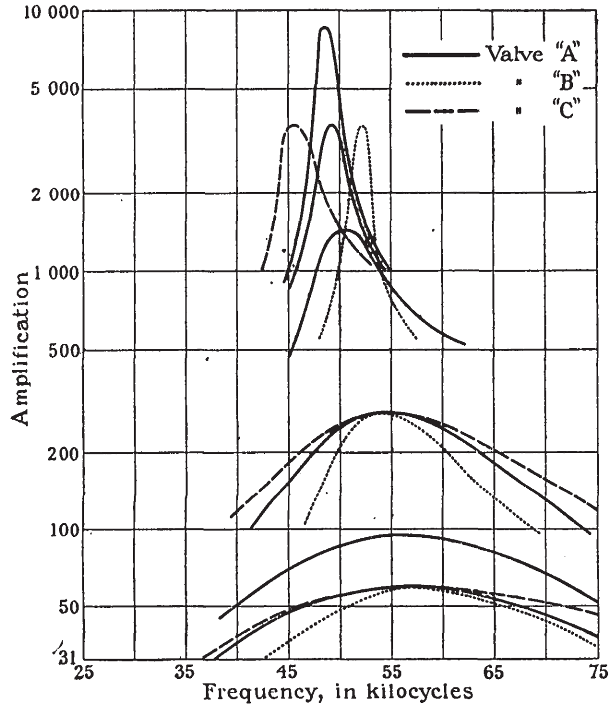

FIG. 3.

for a wide range of values and also gives a better representation of the actual effect of the amplifier as regards the volume of sound. Results with valve A are shown for six different settings of grid potential. When valves B and C were in use the amplifier was adjusted to give the same maximum amplification as in three of the A curves, for ease of comparison. The grid potentials required are shown in Table 2.

TABLE 2.

Peak amplification at stated grid potential	Grid potentials (volts)		
	A	B	C
58	1·00	− 0·2	1·30
93	0·5	—	—
280	0·25	− 0·26	0·64
1 470	0	—	—
3 600	− 0·1	− 0·49	0·43
8.300	− 0·15	—	—
self-oscillation	− 0·19	− 0·50	0·41

It will be noticed that the high amplification factor of valves B and C causes their range of adjustment to be smaller than that of valve A, consequently their control is rather more critical. The ease with which they go into oscillation, on the other hand, increases with the mutual conductance; for valve C, though it has a lower value of μ than B and a higher impedance than A, oscillates much sooner than either of them.

From Fig. 3 it will be noticed that as the damping is reduced the resonant frequency becomes lower, and that the higher the mutual conductance of the valve the more marked is this effect. With valves A the frequency is lower with decrease of anode current, whereas with different valves and constant amplification the frequency is decreased as the anode current

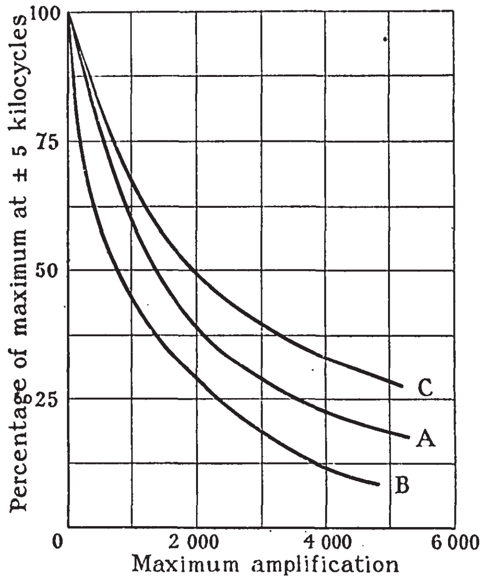

FIG. 4.

increases; hence the effect cannot be due to the variations of the steady flux-density of the iron cores of the transformers. Neither can it be caused by the variation of equivalent shunt resistance, for according to theory a decrease of resistance, i.e. an increased damping, should reduce the frequency, whereas the opposite is shown by the curves.

The author considers that the most likely explanation is the Miller effect,* which causes the maximum amplification to be obtained at a frequency lower than that given by the expression

$$\omega = \frac{1}{\sqrt{(LC)}}$$

i.e. when the anode circuit is inductively reactive, and this effect comes increasingly into action as amplification is made to depend on inter-electrode capacity feed-back. For the same reason it is unsafe to draw conclusions on an assumption that the resonant frequency as shown by the curves is a true resonance in the sense of the tuned circuits being capable of representation by a pure resistance.

* J. M. MILLER: *Scientific Papers of the Bulletin of the Bureau of Standards,* No. 5351.

The most important information supplied by these curves is the amount of side-band cut-off in the various cases. For convenience the modulation of the carrier will be assumed to extend to 5 kilocycles on each side, this being usually considered to be the highest note frequency which is necessary in order to obtain reasonably good reproduction in a supersonic type of receiver, where extreme low-frequency frequencies may well be sacrificed to selectivity. The curves in Fig. 4 have been derived from Fig. 3 to show the maximum amplification that can be obtained with each type of valve, it being stipulated that the 5-kilocycle notes shall not be reduced to less than a certain percentage of their strength relative to peak amplification. For example, a 50 per cent amplification at the side-band extremes, which is compatible with fairly satisfactory quality, allows one to run up to an amplification of 2 000 with C valves, but only 800 with B valves. The permissible amplification is, in fact, roughly proportional to the mutual conductance of the valves. Where quality is a secondary consideration to utmost selectivity, valves with a low value of mutual conductance are suitable. For ease of control and large amplification, however, while preserving the high notes, the best valve is one of the type which is commonly used to work a loud-speaker. In all-round work valve A (which is the standard type for this amplifier) is probably a fair compromise.

It may be as well to observe here that the volume of sound ultimately obtained does not increase so rapidly with reduction of damping as the figures of maximum amplification would seem to indicate, as they refer to the carrier, whereas it is the side-bands which are responsible for the sound, and their average amplification is less than that of the carrier to an extent which increases with sharpness of resonance.

Further measurements, which are not given in detail, indicate that with high maximum amplification, say over 1 000, the amplification falls off with increase of input; i.e. the output tends to become constant. On the other hand, the reverse is true with low amplification.

The results given indicate the performance of a typical amplifier using a limited number of stages worked fairly efficiently. The alternative, which cannot be considered in a commercial set, is to use a large number of stages worked inefficiently as regards amplification per stage. It is then possible, if the circuits are very carefully designed, to get a steep cut-off at any desired frequency, thus obtaining the maximum selectivity concomitant with satisfactory reproduction of overtones in speech and music, without which an unpleasant "drumminess" results. The amplifier described, with which the user may obtain what he wants in the way of a compromise between tone and selectivity, is satisfactory for general purposes.

Results may be summed up as follows:—

(1) Valves with high mutual conductance give broader resonance peaks for a given amplification, and go into oscillation more readily, than those with low.
(2) Valves with low magnification factor are more easily controlled than those with high.
(3) As amplification goes up with change of grid potential, peak frequency is reduced.
(4) Amplification increases with input amplitude with a highly damped amplifier, and vice versa.

MEETINGS OF THE WIRELESS SECTION.

58TH MEETING: 5 JANUARY, 1927.

Prof. C. L. Fortescue, O.B.E., M.A., Chairman of the Section, took the chair at 6 p.m.

The minutes of the meeting of the Wireless Section held on the 1st December, 1926, were taken as read and were confirmed and signed.

An informal discussion on "The Acoustic Problems of Microphones and Loud-Speakers" was introduced by Mr. G. H. Nash, C.B.E.

On the motion of the Chairman a vote of thanks to Mr. Nash for opening the discussion was carried with acclamation, and the meeting terminated at 7.55 p.m.

59TH MEETING: 2 FEBRUARY, 1927.

Mr. E. H. Shaughnessy, O.B.E., took the chair at 6 p.m.

The minutes of the meeting of the Wireless Section held on the 5th January, 1927, were taken as read and were confirmed and signed.

An informal discussion, opened by Mr. C. F. Phillips, took place on the subject of "The Purpose and Design of Broadcast Receivers." On the motion of the Chairman a vote of thanks to Mr. Phillips was carried with acclamation, and the meeting terminated at 7.45 p.m.

60TH MEETING: 2 MARCH, 1927.

Prof. C. L. Fortescue, O.B.E., Chairman of the Section, took the chair at 6 p.m.

The minutes of the meeting of the Wireless Section held on the 2nd February, 1927, were taken as read and were confirmed and signed.

A paper by Mr. T. L. Eckersley, entitled "Short-wave Wireless Telegraphy" (see page 85), was read and discussed. On the motion of the Chairman a vote of thanks to the author was carried with acclamation, and the meeting terminated at 7.55 p.m.